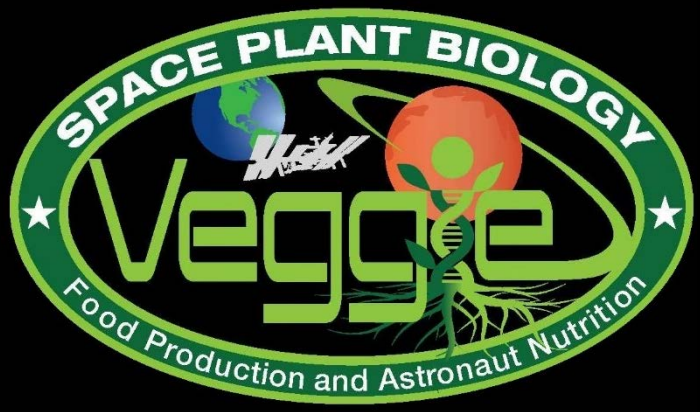


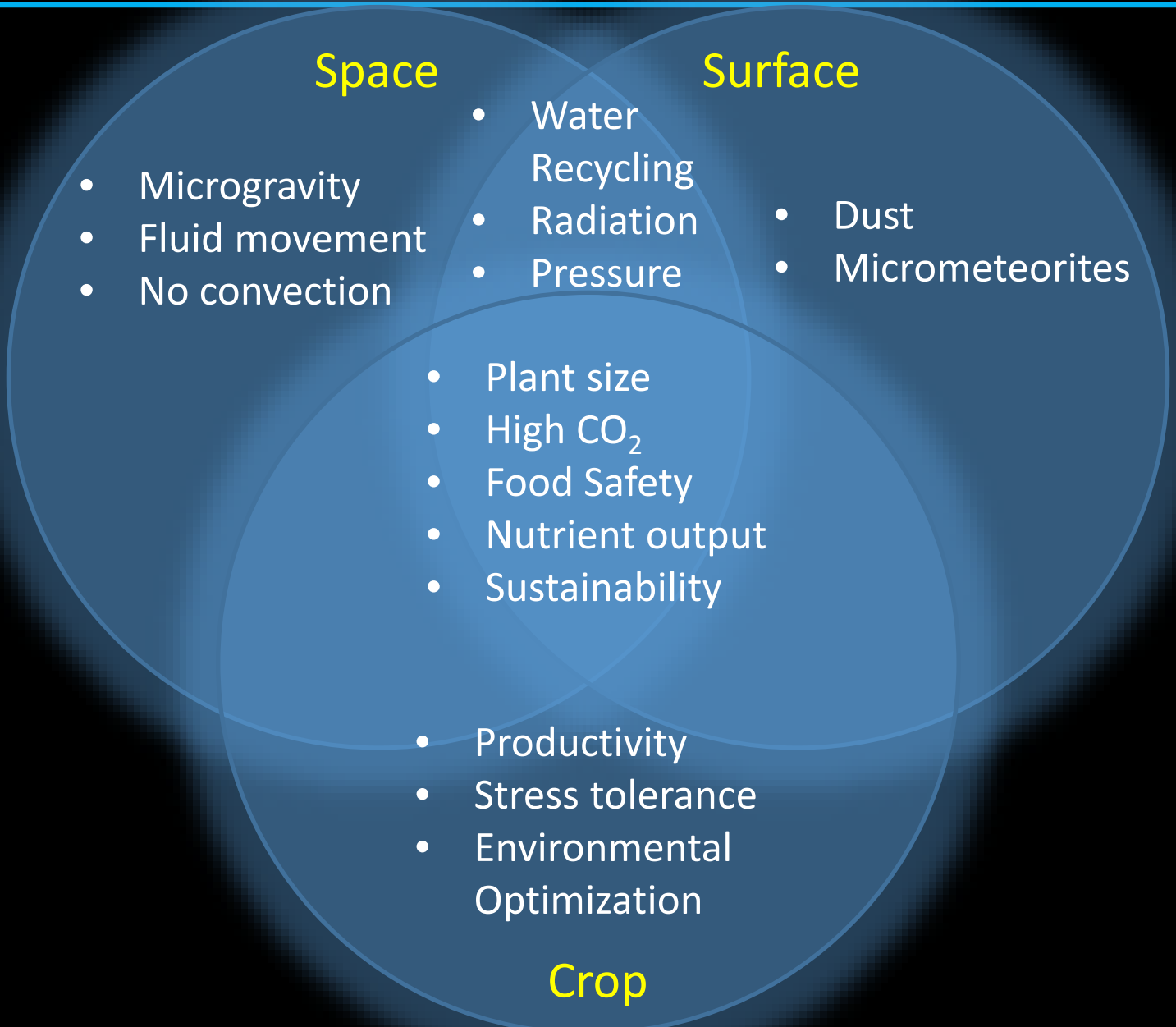
Food Production for Space Exploration

Gioia Massa
Project Scientist
NASA, Kennedy Space Center
Exploration Research and Technology Programs

Space Food Production

- Goal: To produce safe, nutritious, appealing food to supplement a stored diet
  - As mission duration increases, a greater percentage of the diet might be produced
- Key Factors:
  - Production in controlled environments
    - Any solar light reduced and indirect
    - High CO_2 levels likely (ISS ≥3000 ppm)
    - Common environments for multiple crops
    - Crop scheduling is critical
  - Power, mass, volume, and crew time must be minimized
  - Sustainability - minimizing waste, nutrient recycling
  - Biotic stresses - carried from Earth, mutation
  - Abiotic stresses - related to micro or fractional gravity
  - Opportunities:
    - Designer plants for space growth and nutrition
    - Automation
    - In Situ Resource Utilization (Regolith, CO_2, water)

Space Food Production Challenges



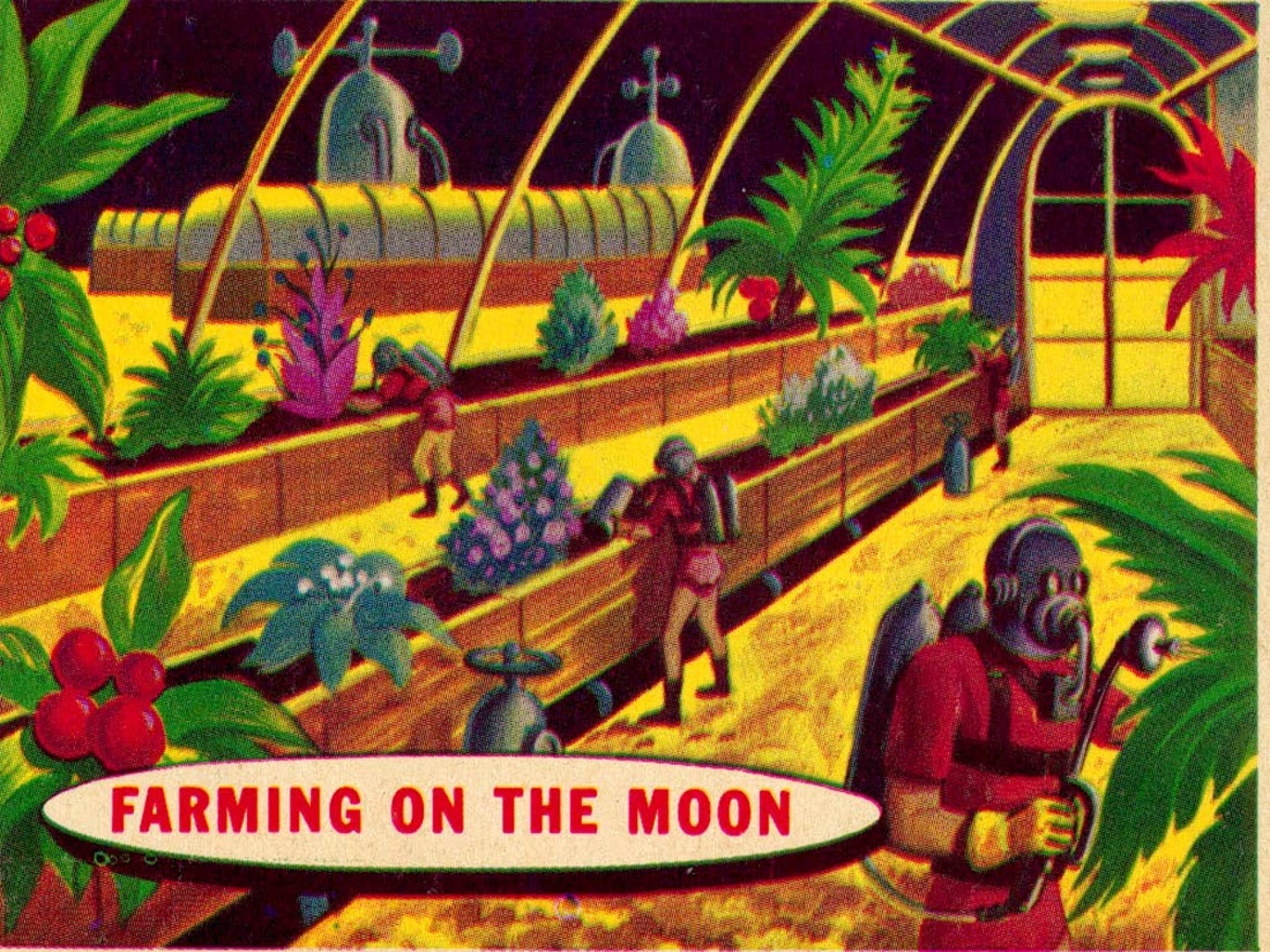
61

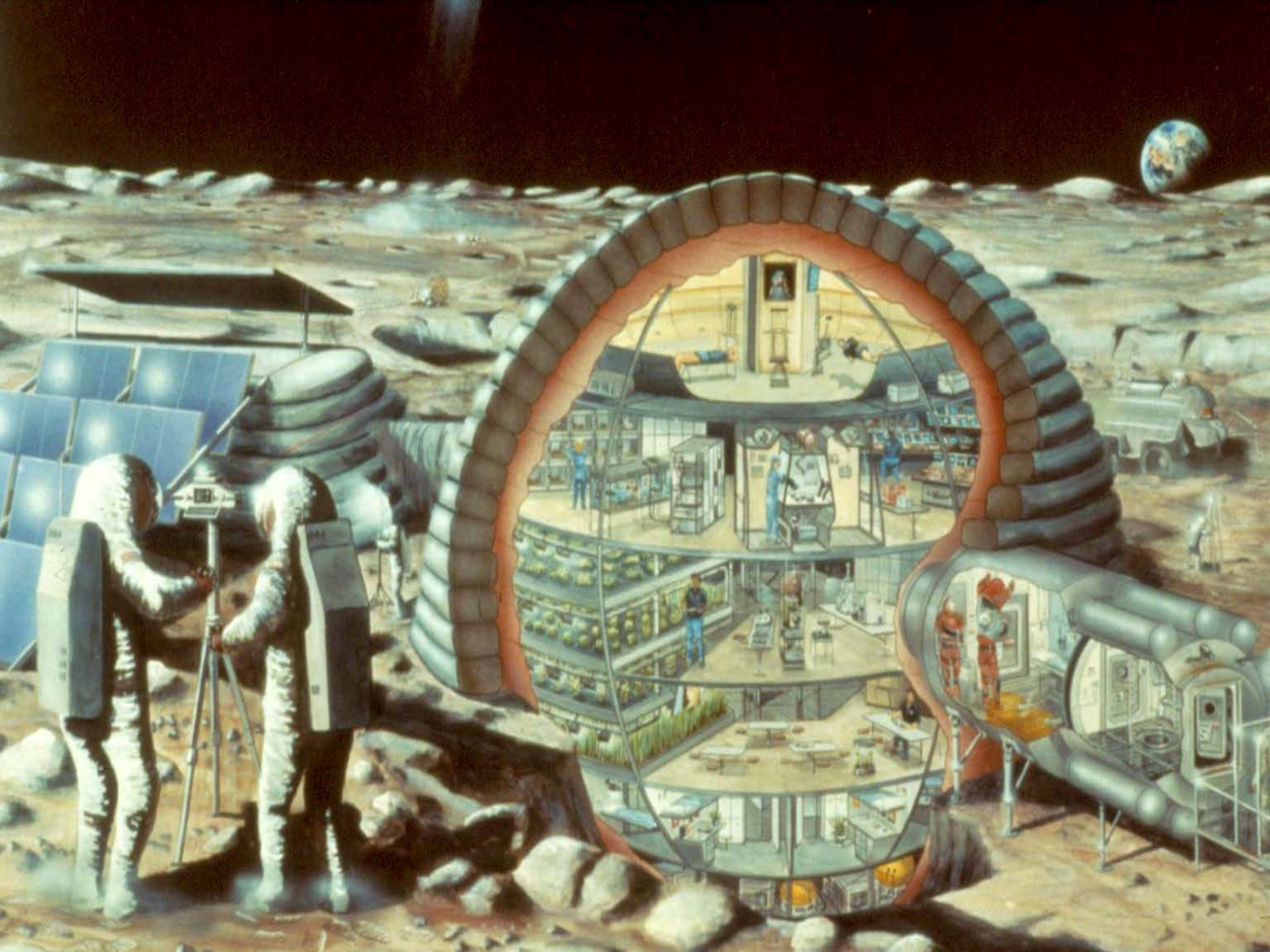
FARMING ON THE MOON

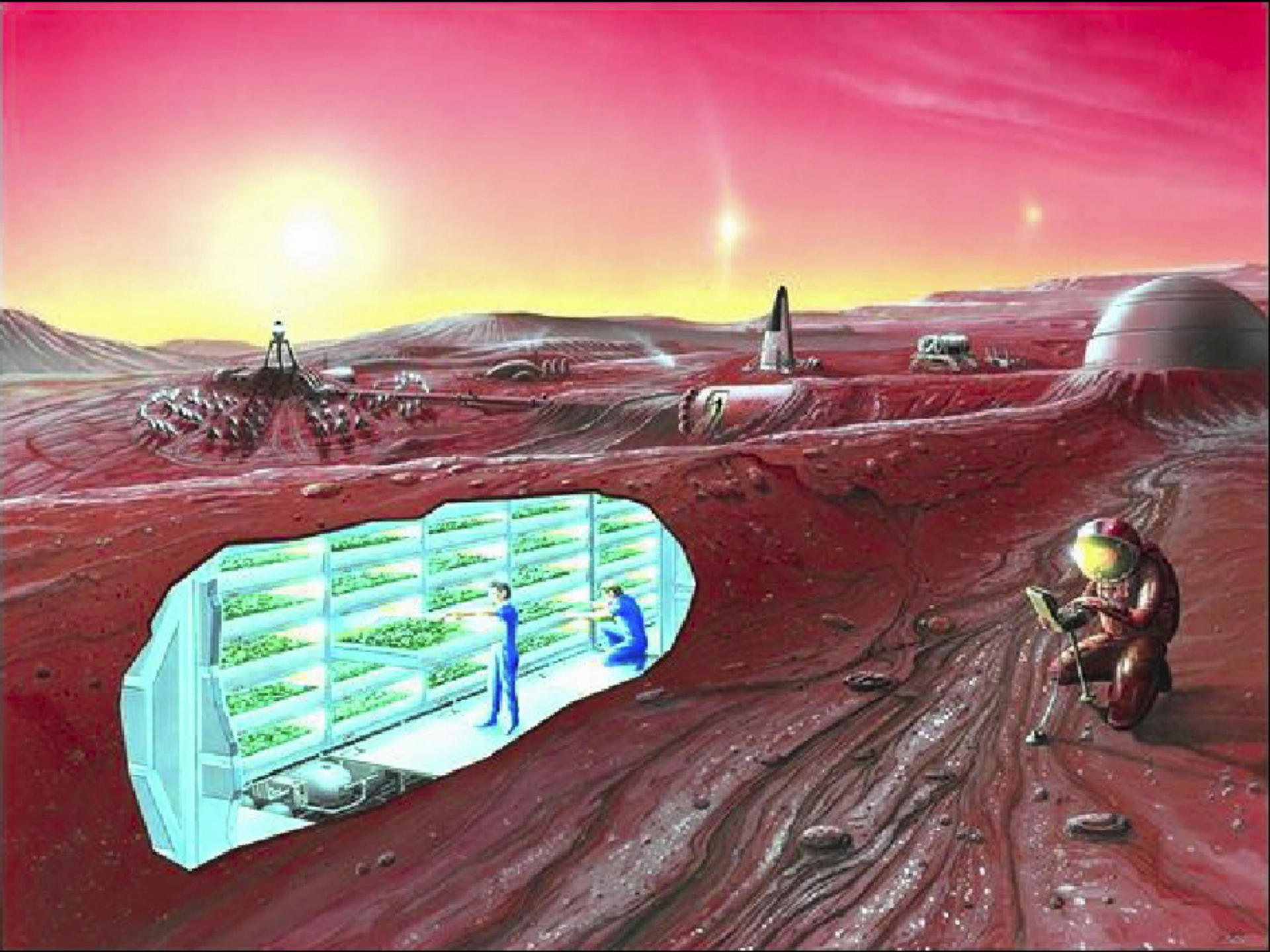
Farming on the moon will be mostly done 'indoors,' under a large plastic dome. Carbon Dioxide will be pumped in and sunlight will pour down on the plants. Special types of plants will be developed to give high energy foods to compensate for the pioneers' lack of meat. Certain plants like strong cactus that can withstand the blistering rays of the sun, will be able to grow 'outdoors' on the moon.

See Card No. 62—MOON TRAINS

TARGET: MOON


FARMING ON THE MOON



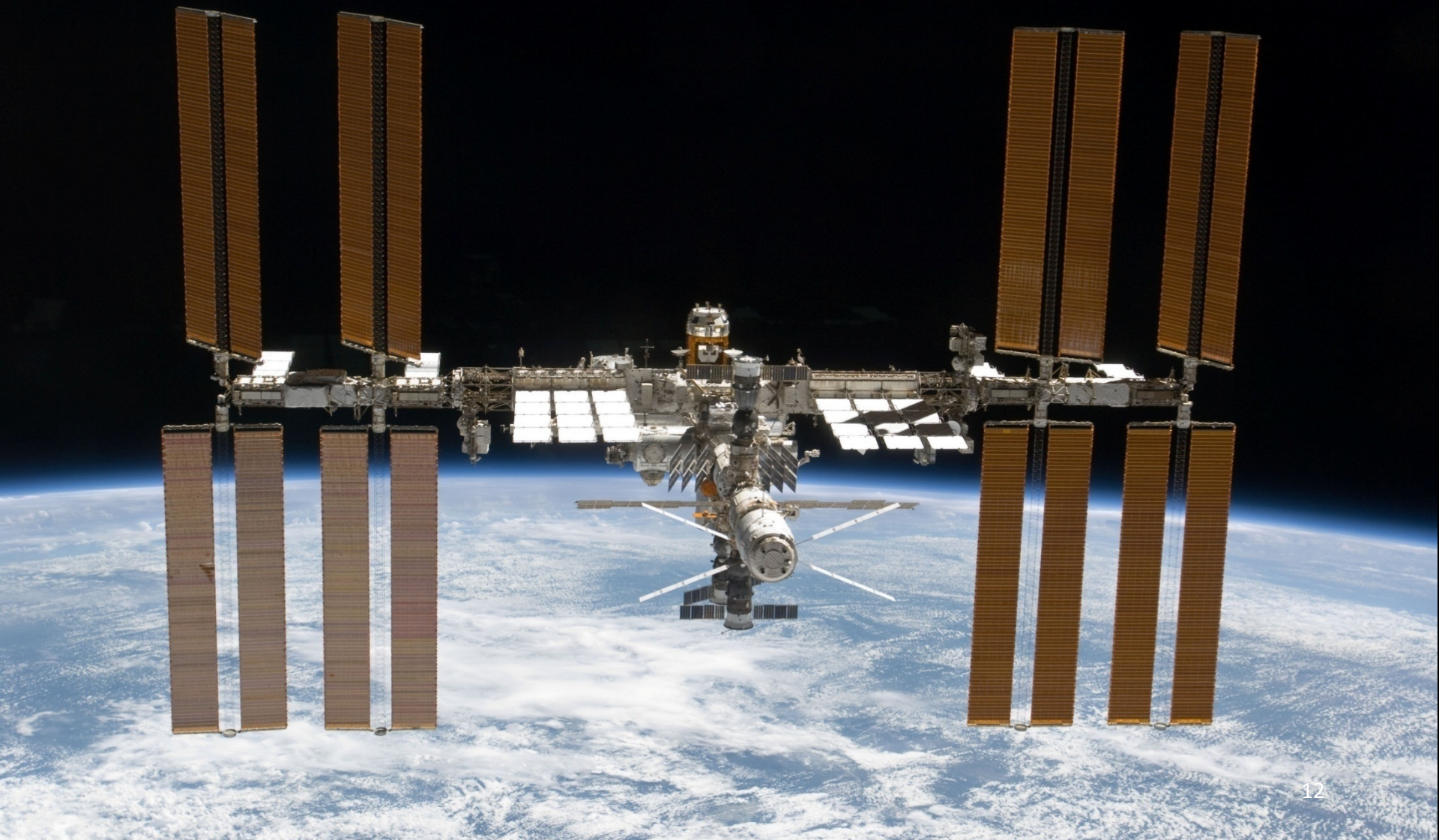


Plant Factories

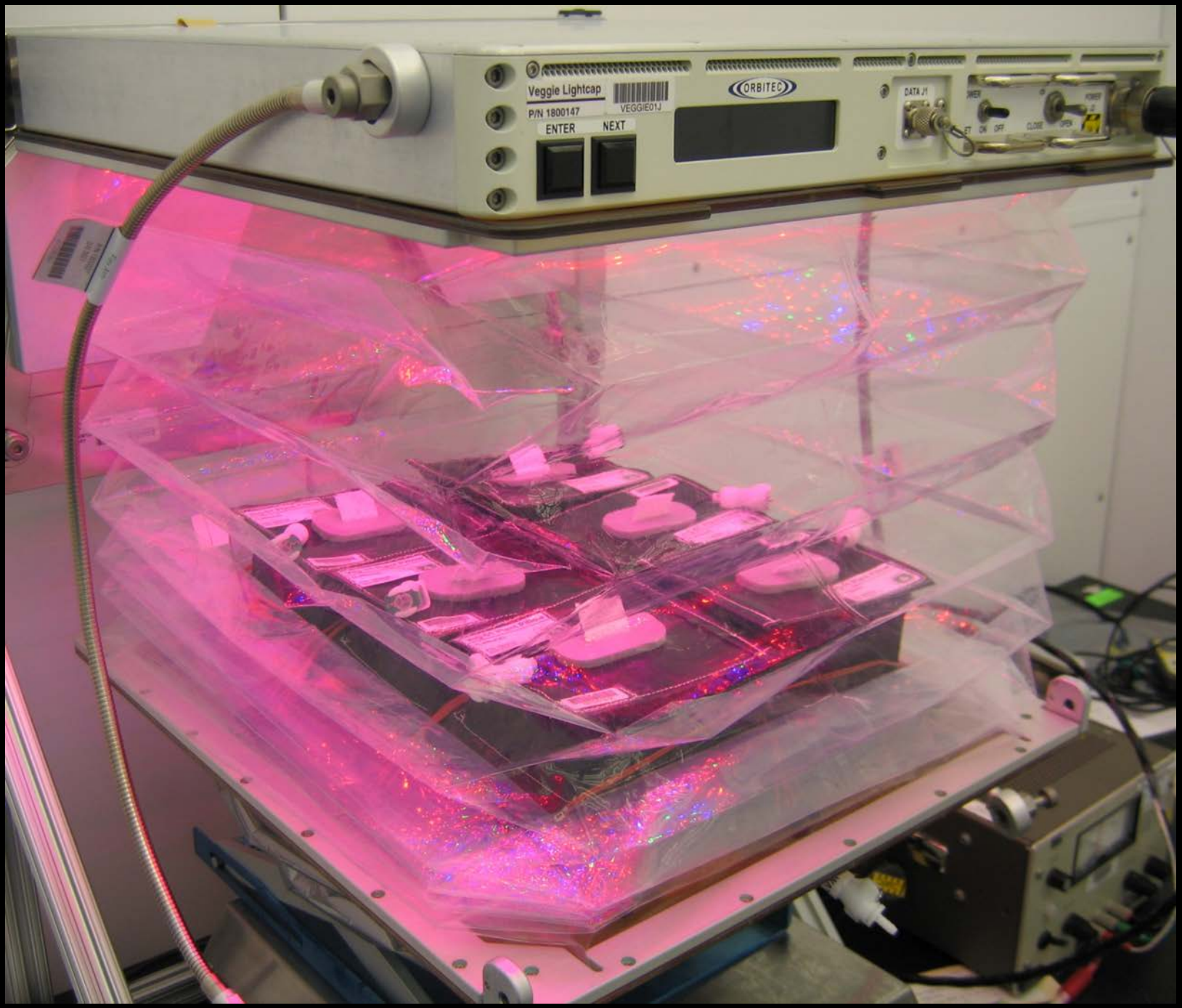
South Pole Greenhouse

Photo from “On the Ice” Blog of Russ Durkee

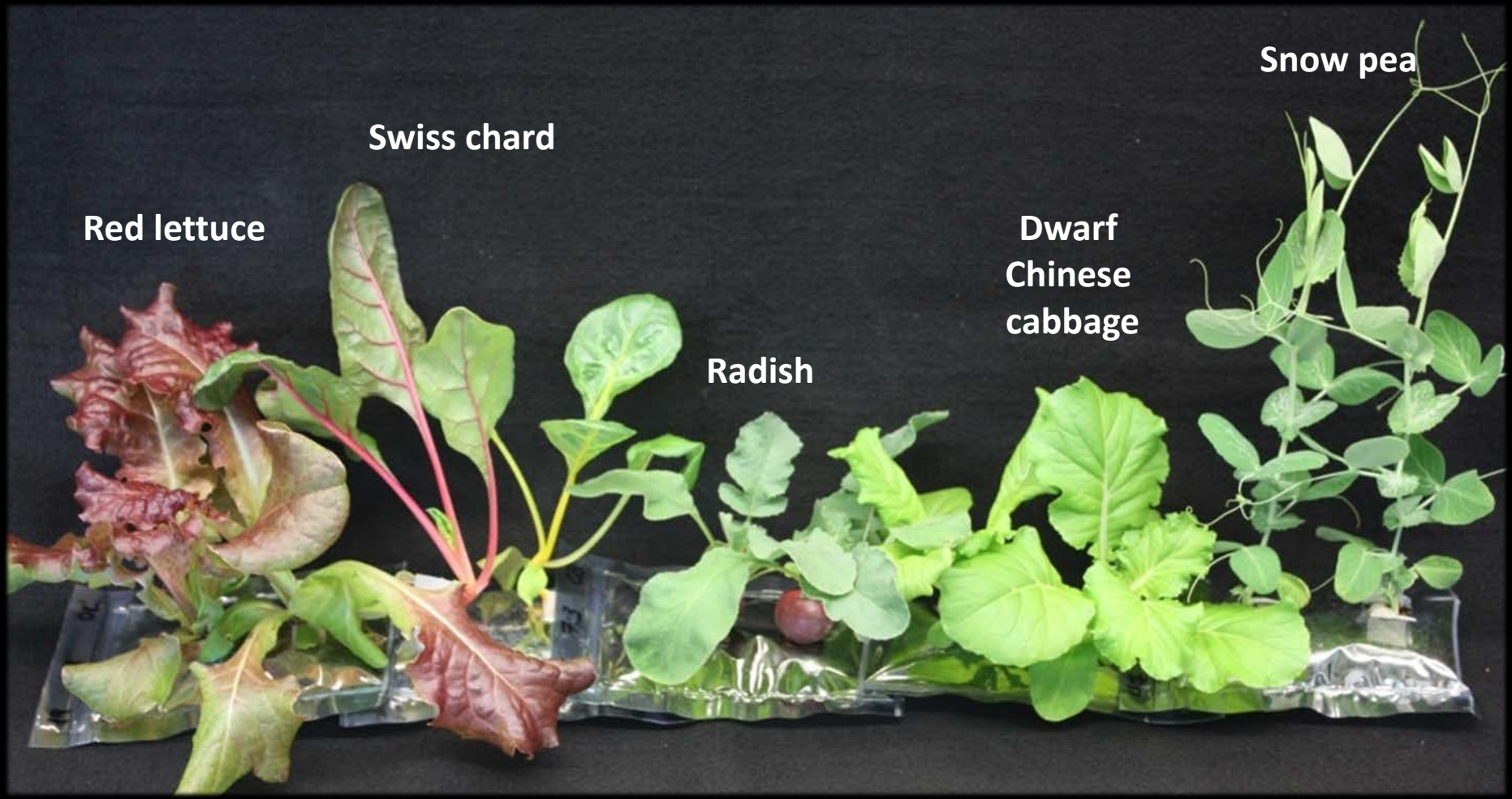
The International Space Station



Designed and built by Orbital Technologies Corporation (ORBITEC)



Example crops tested in plant pillows



Crop Selection for VEG-01

- Reliable germination
- Rapid growth
- Low native microbial levels
- Palatability / acceptability
- Attractiveness
- Antioxidants

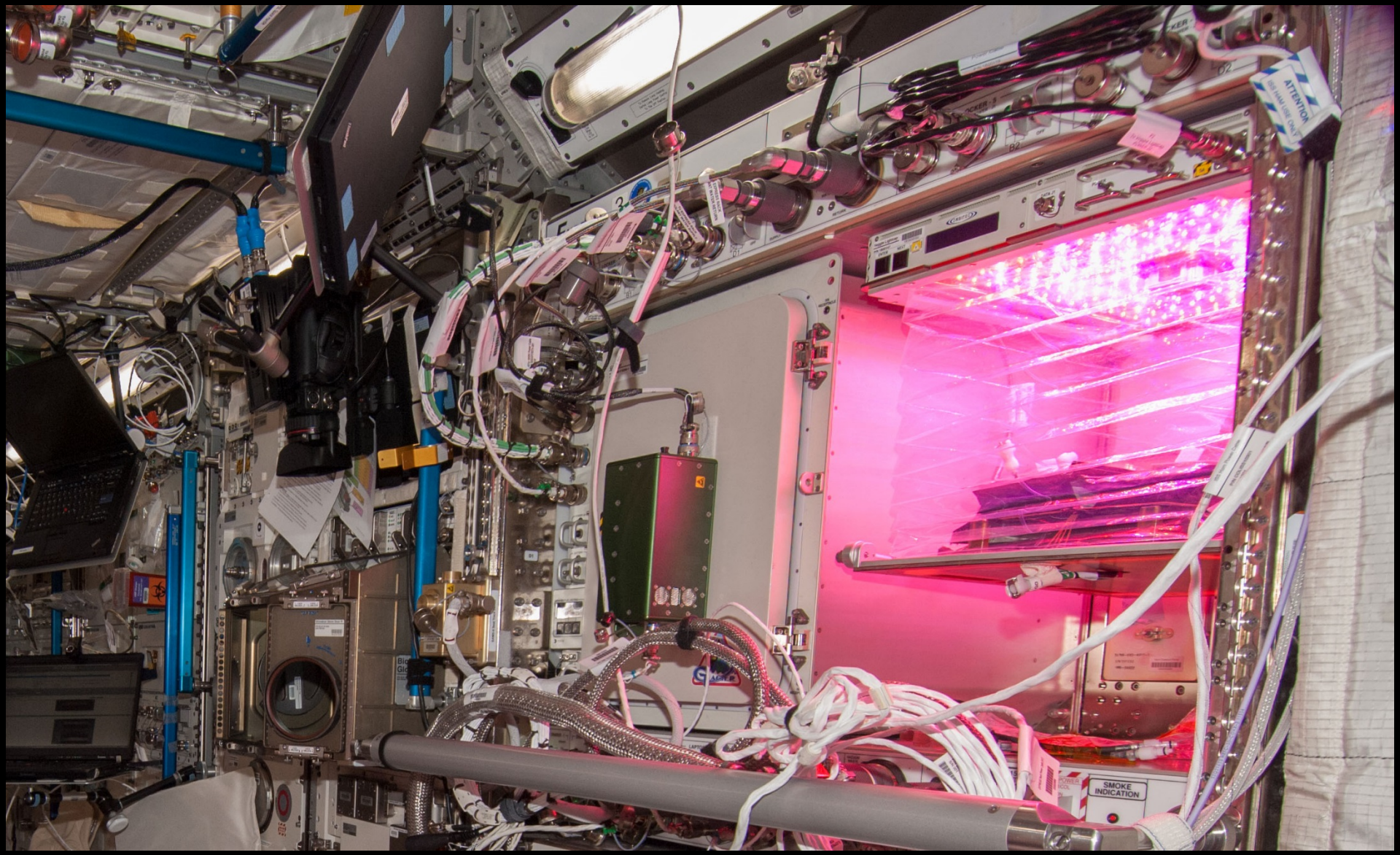
'Outredgeous'
red romaine lettuce

Sent two sets of 'Outredgeous' lettuce and one set of 'Profusion' zinnia pillows

Veggie Installation

Veggie was installed in the ISS Columbus Module on 5/7 by Steve Swanson and Rick Mastracchio

Veg-01 initiation



Veg-01 wick opening (3 DAI)

Veg-01 on-orbit wick opening assisted seedling growth (3 days after initiation)

Veg-01 plant thinning (7 DAI)

Veg-01 on-orbit plant thinning operation eliminated competition for resources

Veg-01 plant thinning (7 DAI)

Veg-01 on-orbit plant thinning operation eliminated competition for resources

- Pillow B did not germinate
- 5 pillows contained seedlings

Veg-01 water stress

Veg-01 on-orbit plants exhibited low water response characteristics. Water was added directly to pillows to ensure water availability for the seedlings.

Veg-01 water stress

Plants in pillows A and C grew well
Plants in pillows D, E, and F exhibited stunting and water stress
D ultimately recovered and E and F died

Veg-01 Harvest (33 DAI)

Veg-01 Harvest

Environment Inside Veggie during VEG-01

Humidity (%)

Temperature (°C)

HOBO Data Logger
moved to right side

Possible pillow overfill?

Harvest

60
55
50
45
40
35
30
25
20

5/7/2014
5/12/2014
5/17/2014
5/22/2014
5/27/2014
6/1/2014
6/6/2014
6/11/2014

VEG-01 Sample Analysis

- Fresh Mass
- Culturable microbial assessment:
  - Plants
  - Water
  - Pillow components
- Identification of cultured microbes
- RNA sequencing / ID of total microbial population
- Anthocyanin/Antioxidant/Phenolic Analysis
- Elemental analysis of plants and water
- X ray tomography of pillows

Fresh Mass

	Flight	Ground
Number	3	5
Average FM	20.61 g	15.29 g
SD FM	11.66 g	9.60 g
Max	31.51 g	26.11 g
Min	8.31 g	2.81 g

Sample priority:

1. Microbial analysis
2. Anthocyanin/Antioxidant/Phenolic Analysis
3. Elemental analysis of plants

Only samples of >19 g could be used for all three.

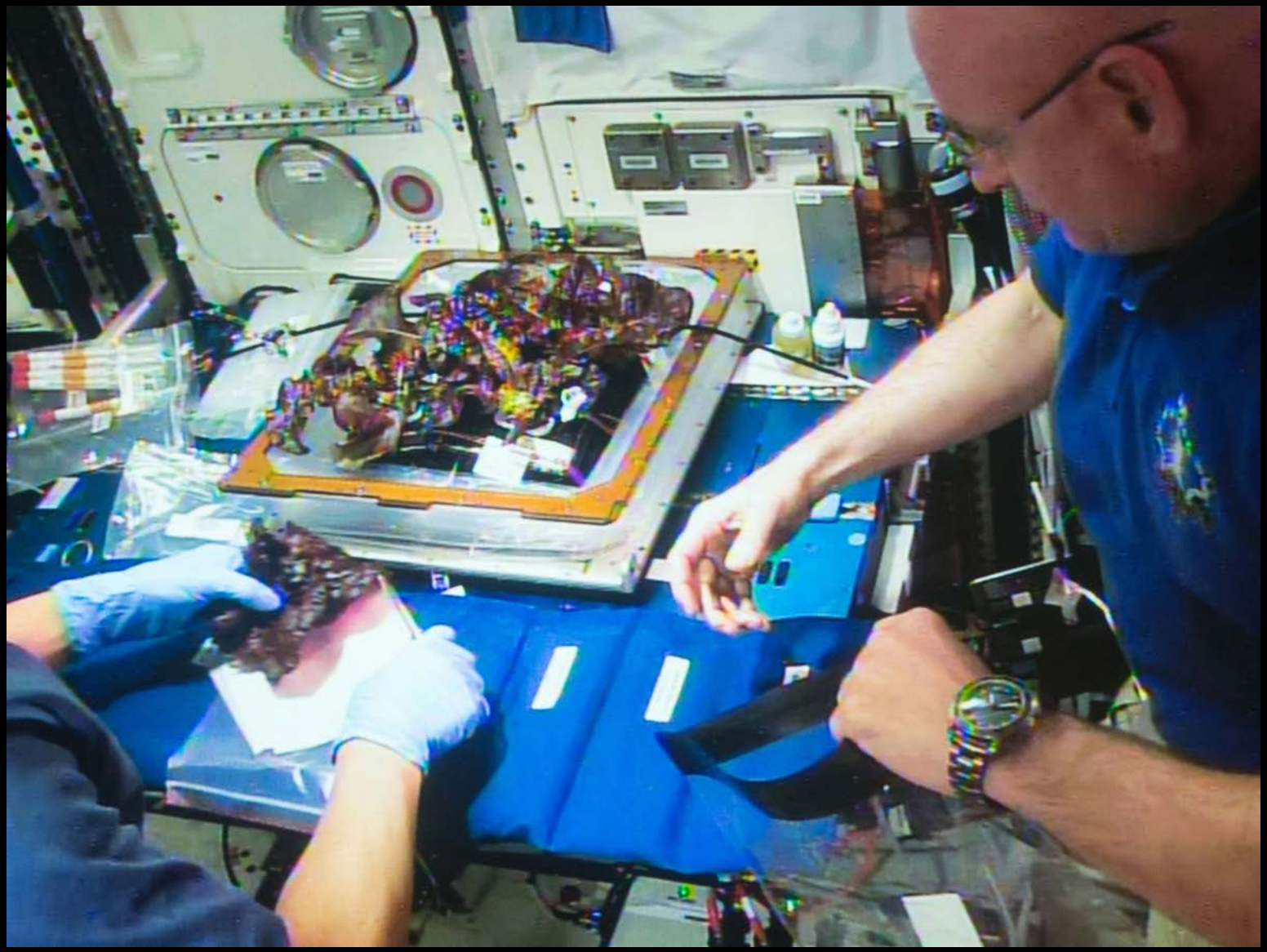
Microbial Assessment of Plants

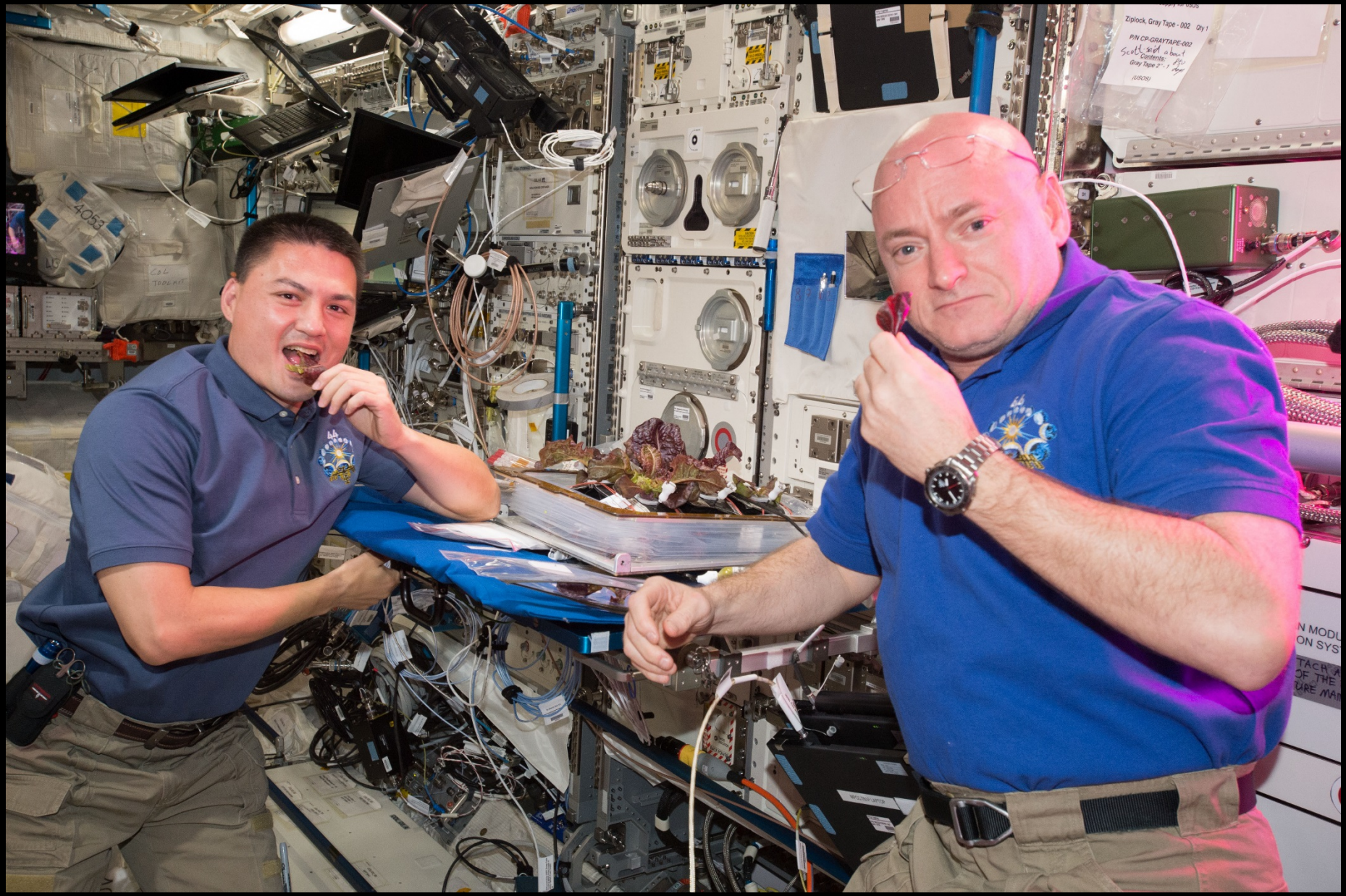
- *E. coli, S. aureus, Salmonella* sp. not found on any plants.
- Aerobic plate counts less than limit for non-thermostabilized food on all flight plants and all but one ground plant (unexplained).
- Total yeasts and molds all below limit except on one flight plant (plant C, the largest, slightly over).
- Bacterial and fungal species isolated appear to be typical station microbes. There were some differences in the community from the ground set.
- Crew were approved to consume produce with precautionary wiping (this took > 6 months!).

Veg-01 Second Crop

- Modified watering procedures, increased photo frequency
- Initiated by Scott Kelly on July 8, 2015 from seeds previously sent
- Grown by Scott Kelly and Kjell Lindgren
- Water stress observed but astronauts intervened and grew 5 plants
- ½ the produce for consumption, ½ for science
- Plants harvested Aug. 10, 2015, live on NASA TV
- Science samples frozen and returned May, 2016.

Sanitizing Produce




Ziplock, Gray Tape - 002 Qty 1
P/N CP-GRAYTAPE-002
Scott sed about
Contents:
Gray Tape 2" - 1
(USOS)

Astronaut Comments

- Scott Kelly
  - the logistical complexity of having people live and work in space for long periods
  - the supply chain that is required
  - For Mars, need a space craft that is more self-sustainable with regards to its food supply
- Kjell Lindgren
  - benefit of eating the fresh food
  - contribution that plants have to the ISS ecosystem
  - psychological benefit - it's really fun to see green growing things in the sterile environment of the ISS

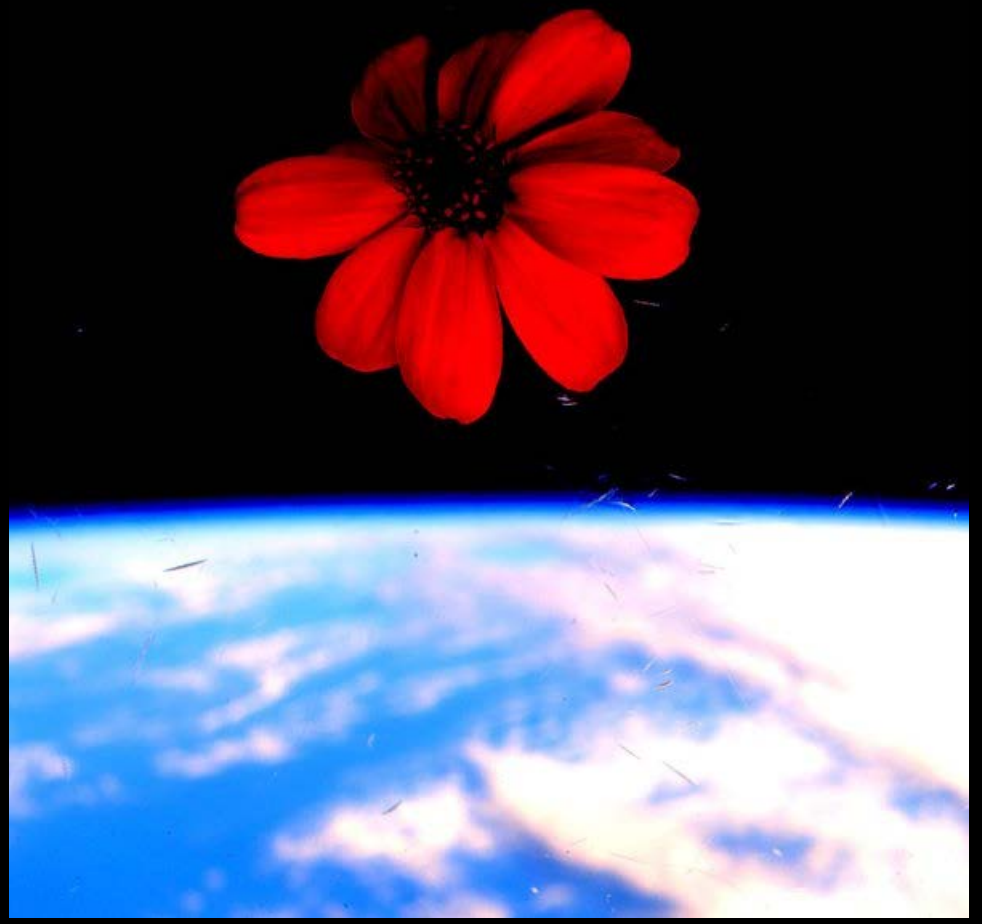
Veg-01 Third Crop - Zinnia

- Directly watered plants after initiation, decreased photos to reduce crew time demands
- Initiated on Nov. 16, 2015 from seeds previously sent
- Grown by Kjell Lindgren and Scott Kelly
- Plants received too much water; fungus developed
- Mitigation attempted but several plants were lost before flowering
- Autonomous gardening started in Dec.
- Plants harvested Feb. 14, 2016
- Samples frozen and returned May, 2016

Zinnia on ISS

Zinnia data to inform on:

- Long term watering
- Microbial issues
- Flooding and air flow
- Mitigation strategies
- Flower development
- Seed formation and viability
- Human factors
- Chemistry and microbiology
- Plant pathogens on ISS



Water Issues / Consequences

Guttation and Leaf Curling

Fungal Development
& Abnormal Growth

Veg-01 Zinnia Flight Flowers

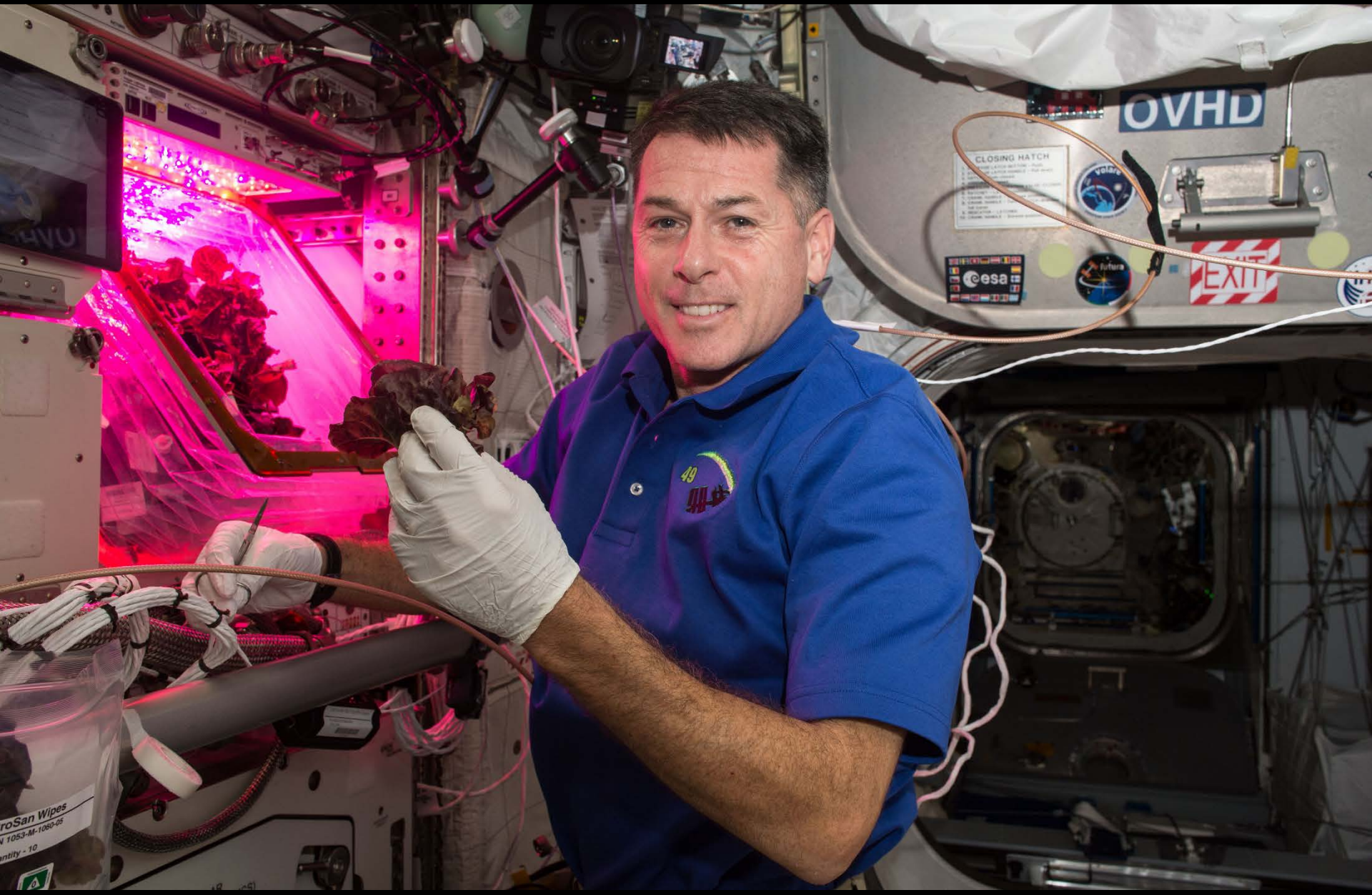
Zinnia Action Shots

Valentine’s Day Bouquet on the ISS

Next Steps

- Veg-03 ‘Tokyo bekana’ cabbage / ‘Outredgeous’ lettuce
  - Launched on CRS-8 (Feb. 8, 2016)
  - Lettuce grown – Final harvest Dec. 28, 2016
  - Cut-and-come-again testing
- Developing plans to pre-stage pillows and send seeds separately
- Crop testing of leafy greens, peppers, tomatoes - at KSC and in schools
- Testing light quality and fertilizer for Veg-04 ‘Tokyo Bekana’ and Veg-05 dwarf tomato

VEG-03A Cut-and-Come-Again

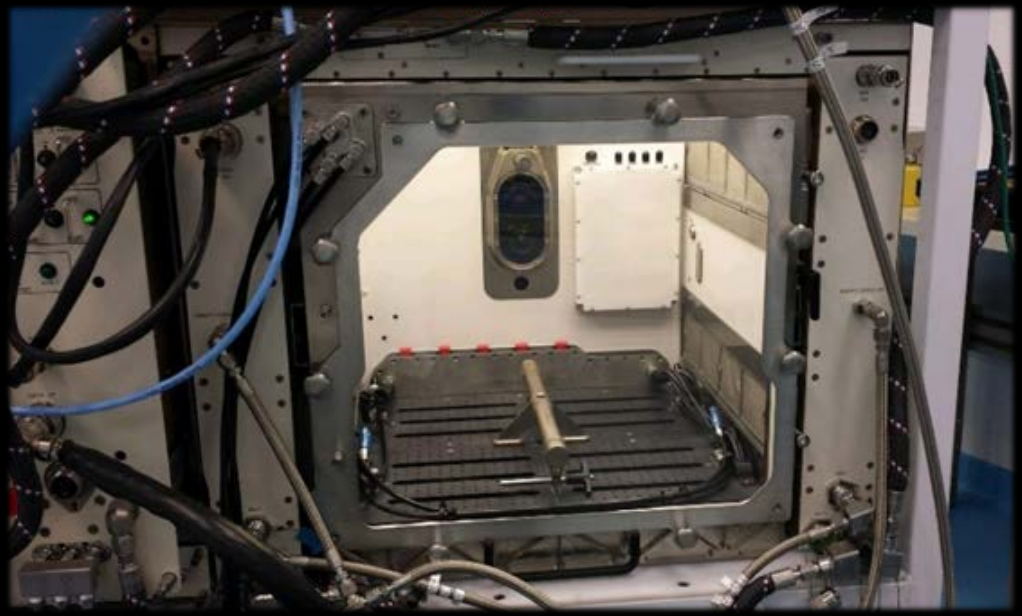


Thank you!

- Veggie and VEG-01 teams at KSC and ORBITEC
- Astronauts Steve Swanson, Rick Mastracchio, Scott Kelly, Kjell Lindgren
- Payload Operations and Integration Center

Veggie
Send more seeds!
We are hungry.
-Rick Mastracchio

- NASA's Space Life and Physical Sciences, ISS Program, Human Research Program



Next to fly:
NASA's Advanced Plant Habitat